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ALUMINUM-SILICON ALLOYS PRODUCED BY
POWDER METALLURGY METHODS

by

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ABSTRACT

Development of hypereutectic aluminum-silicon alloys has been handicapped by the behaviour of the primary silicon phase which forms large particles and segregates during solidification. The use of powder metallurgy techniques has made it possible to prepare alloys with higher percentages of refined silicon than can be produced by casting. The increased silicon contents result in alloys that have lower coefficient of thermal expansion and improved wear resistance.

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INTRODUCTION

Hypereutectic aluminum-silicon casting alloys have attracted considerable attention because of their low coefficient of thermal expansion and good wear resistance, both of which improve with increasing silicon content. Unfortunately, these alloys solidify over a wide temperature range permitting the primary silicon to separate as large particles that tend to segregate, giving inferior mechanical properties and poor machinability. The size of the primary silicon particles increases with increasing silicon content and this has made it difficult to develop useful alloys with higher silicon contents. Much of the experimental work on the alloys has been carried out with the aim of obtaining a refined silicon phase at high silicon levels. The degree of refinement achieved so far has been obtained only in chill castings poured from melts treated with special refining agents. The maximum refined silicon content attained in this manner to date is about 23%.

This article describes how powder metallurgy techniques have been used to prepare aluminum-silicon alloys containing up to 45% silicon in which the primary silicon is refined to a degree not previously accomplished.

PREPARATION OF HIGH-SILICON ALUMINUM POWDER ALLOYS

Three hypereutectic aluminum-silicon alloy powders with nominal silicon contents of 25%, 35% and 45% were made. The initial step in producing the powders was to prepare alloy melts by conventional means. The first melts made were treated with phosphorus (added as copper brazing rod) and magnesium, which have been shown by other investigators to be effective in refining the primary silicon in chill-cast hypereutectic alloys; it was subsequently shown that refining additions were not necessary for the powder product. The brazing rod and magnesium additions resulted in 0.36% copper and 1% magnesium being present in the alloys.

The melts were transferred to an apparatus in which jets of compressed air atomized a stream of molten metal into particles which were quenched in water. The powders were dried and screened through a 100 mesh sieve, the +100 mesh fraction being discarded.

Two methods were used to consolidate the powders. In one method, the powders were cold compacted at 60,000 psi and then hot pressed at 700°F with the same pressure. The resulting compacts, which were 2 inches in diameter, were extruded at 64,000 - 96,000 psi and 750°F to $\frac{1}{2}$ inch-diameter rod. The 25% and 35% silicon alloys extruded without difficulty, but the 45% silicon alloy could not be extruded even when the pressure was increased above 96,000 psi; it is possible that the latter composition would extrude at a higher temperature.

In the other method of consolidation, the powders were first isostatically cold compacted at 10,000 psi to give compacts of 1 5/16 inches diameter. The compacts were then hot pressed, using three conditions of temperature and pressure: 750°F and 38,000 psi, 1020°F and 38,000 psi, and 1020°F and 81,000 psi.

PROPERTIES OF THE POWDER METALLURGY PRODUCT

The microstructure of the -100 mesh fraction of the 35% silicon powder is illustrated in Figure 1; the 25% and 45% silicon powders were similar to this except that the silicon particles were slightly finer in the former and slightly larger in the latter. The primary silicon phase consists of the grey discrete particles within each grain of powder, and Figure 1 shows it to be fine and uniformly distributed, the rapid freezing produced during atomizing having prevented growth and segregation of the silicon. The atomized powder particles are of irregular shape, which is an advantage for compacting.

The degree of refinement obtained is illustrated by Figure 2 which compares the microstructure of the hot compacted 45% silicon alloy with that of a nominal 23% silicon alloy prepared by adding nucleating agents to the melt and casting into a chill mould.

The high degree of refinement attained in the extruded material is shown by Figure 3, which illustrates the microstructure of the extruded 25% silicon alloy.

Some mechanical properties are listed in Table 1. The higher strength obtained for the alloys "with refining additions" is due to the presence in them of magnesium and copper. The comparatively greater strength shown by the 45% silicon alloy with refining additions is thought to be due to the higher pressure applied to this composition in attempting to extrude it. Although the properties listed in Table 1 are quite useful, it is considered that they can be improved by further development work. The hardness of the alloys increased with silicon content and ranged from about 60 to 110 Brinell.

The wear resistance of the alloys was assessed by determining the weight loss incurred by a pin sample (1/8 inch diameter by 1/2 inch long) which had been in dry, loaded contact with a rotating cast iron disc. The test conditions were 1,000 psi and a speed of 200 inches per minute for 1 hour. For comparison purposes, tests were also carried out on a sodium-modified commercial aluminum casting alloy containing a nominal 11.5% silicon. The results, listed in Table 2, show that weight loss decreases with increasing silicon content. Thus, the weight loss for the 45% silicon alloy is half that for the 11.5% silicon casting alloy. However, a comparison cannot be made between the casting alloy and the powder alloys on the basis of silicon content alone because the latter contain more copper and magnesium, which would strengthen the matrix and improve wear resistance. The effect of silicon in improving wear resistance can be seen better by comparing the results for the three powder alloys, all of which had the same composition for the matrix metal; thus, the weight loss for the 45% silicon alloy is 65% of that for the 25% silicon alloy. It is not presumed that the wear-test results would apply to any service

condition, but it seems reasonable to conclude from them that there is a significant improvement in wear resistance when the silicon content is increased from 25% to 45%.

The coefficient of thermal expansion for the three powder alloys and three casting alloys is plotted against silicon content in Figure 4. The silicon percentages plotted for the powders are from chemical analysis of the alloys containing refining additions. Figure 4 shows that increasing the silicon content results in a decrease in the coefficient of thermal expansion, which is about 25% less for the 45% silicon alloy than for a 21% silicon casting alloy. Figure 4 also indicates that an alloy with a silicon content of 58% should have about the same coefficient of thermal expansion as cast iron.

Density determinations carried out on the extruded and hot-pressed materials showed them to be in the range of 97 to 100% of theoretical density.

No machining tests were carried out on the alloys but they all machined satisfactorily during preparation of the test specimens.

APPLICATIONS FOR HIGH-SILICON ALUMINUM ALLOYS

The low coefficient of thermal expansion and good wear resistance of the hypereutectic alloys make them particularly attractive for automotive applications. The cast alloys are being used in pistons, the advantage being the

reduced clearance required for the piston when the engine is cold.

Applications that have been suggested are cylinder liners, brake liners, piston rings and liner-free engine blocks. Other possible uses are in bearings and business machine components.

TABLE 1

Mechanical Properties of Al-Si Alloys
Prepared from Powder

Nominal Composition of alloy	Condition	UTS (kpsi)	0.2% YS (kpsi)	% El. $\frac{1}{4}\sqrt{A}$
<u>With refining additions</u>				
Al-25% Si	Extruded	33	22	8
Al-35% Si	Extruded	32	31	2
Al-45% Si	Hot pressed	40	None	0
<u>Without refining additions</u>				
Al-25% Si	Hot pressed	22	16	3
Al-35% Si	Hot pressed	26	24	2
Al-45% Si	Hot pressed	28	None	3

TABLE 2

Results of Wear Tests on Al-Si Alloys

Alloy	Weight Loss ($\text{gx}10^4$) after 1 hour
Al-25% Si powder. Extruded	132
Al-35% Si powder. Extruded	98
Al-45% Si powder. Hot pressed	86
Al-11.5% Si casting alloy	167

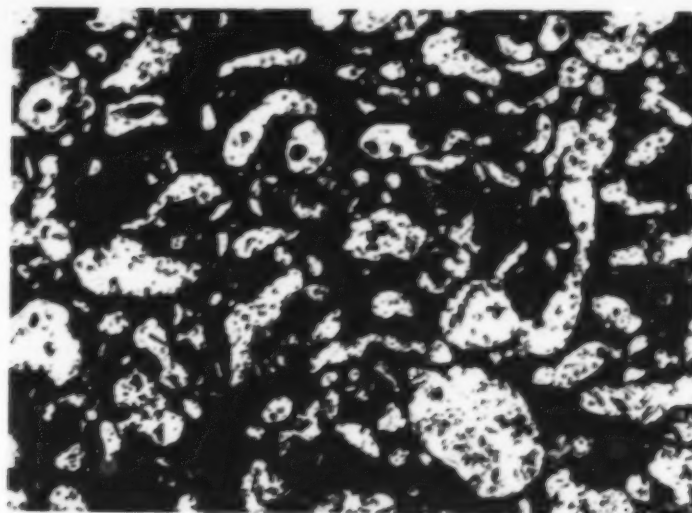
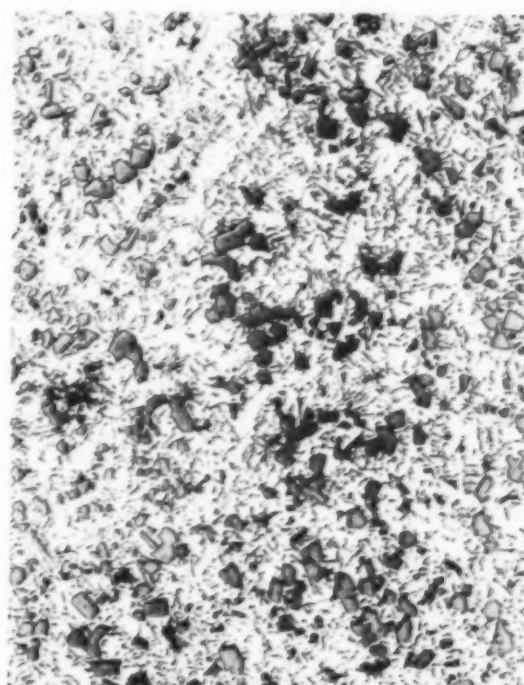
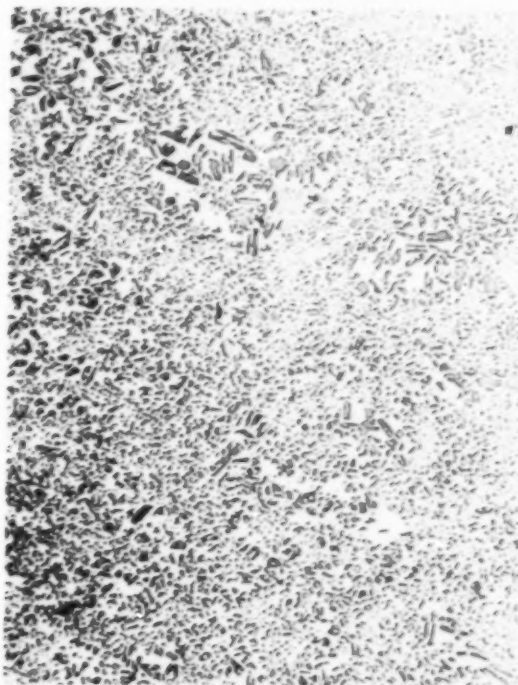


Figure 1. Microstructure of Al-35% Si Alloy Powder.
(100X)



Al-45% Si Alloy Prepared by
Hot Compaction of Powder.

Al-23% Si Cast Alloy.

Figure 2. Microstructures of Powder Product and Casting. (100X)

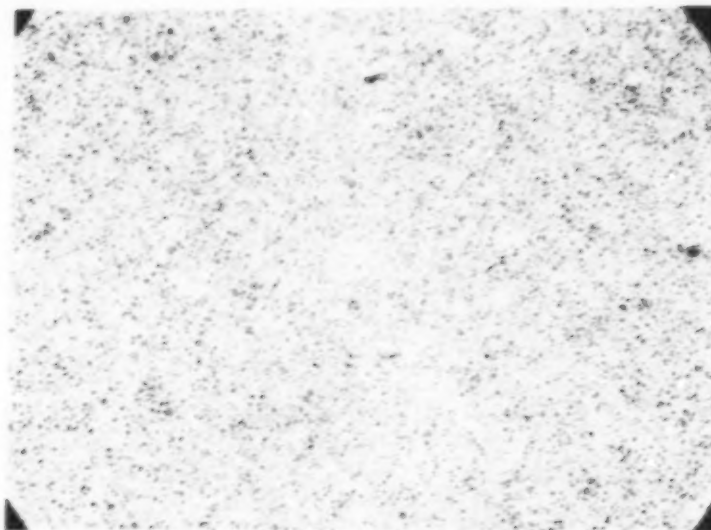


Figure 3. Microstructure of Extruded Al-25% Si Alloy Prepared from Powder. (100X)

